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(71) Applicant *(for all designated States except US)*: LOUGHBOROUGH UNIVERSITY OF TECHNOLOGY [GB/GB]; Loughborough, Leicestershire LE11 3TF (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: VARDAXOGLOU, John, Costas [GB/GB]; 63 William Street, Loughborough, Leicestershire LE11 3BX (GB).

(74) Agents: RAYNOR, Simon, Mark et al.; Abel & Imray, Northumberland House, 303-306 High Holborn, London WC1V 7LH (GB).

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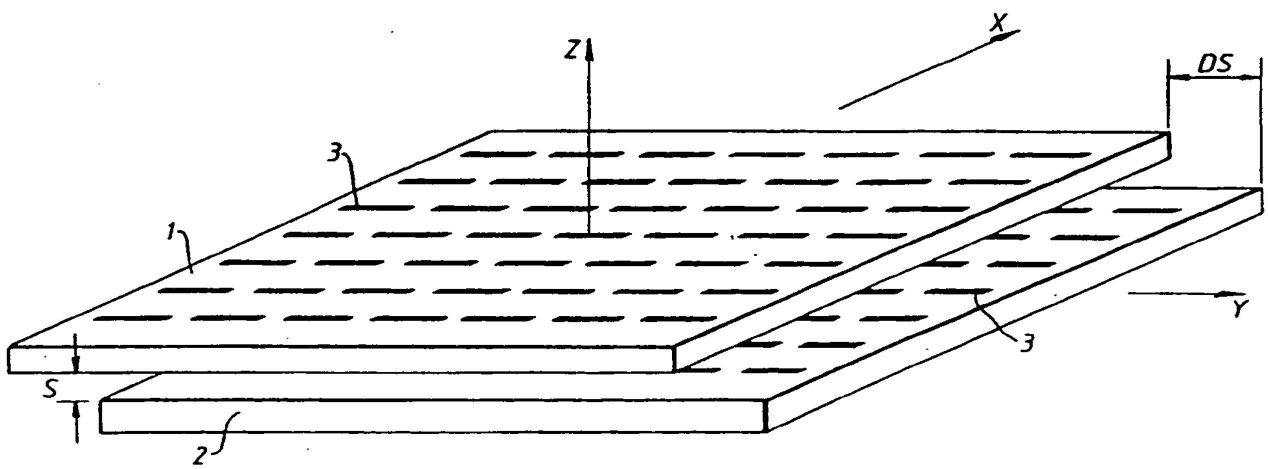

(57) Abstract

A reconfigurable frequency selective surface comprises at least two arrays (1, 2) of elements (3), the arrays (1, 2) being arranged in close proximity with one another so that elements (3) of a first array (9) are closely coupled with elements (3) of a second array (2) adjacent to the first array (1). The first array (1) is displaceable with respect to the second array (2) to adjust the frequency response of the surface.

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Reconfigurable frequency selective surfaces

The present invention relates to a reconfigurable frequency selective surface and a method of reconfiguring the frequency response of a frequency selective surface.

A frequency selective surface (FSS) is an array of antenna elements that acts as a passive electromagnetic filter. The surface may comprise an array of electrically conductive elements on a dielectric substrate or, alternatively, a plurality of apertures in a conductive surface. Electromagnetic waves incident on a surface comprising an array of conductive elements are reflected from the surface only in a narrow band of frequencies and are transmitted at other frequencies. With an array of apertures, electromagnetic waves are transmitted only in a narrow band of frequencies. Such surfaces can be used as multiplexers or radomes in communications systems and can operate at microwave frequencies, including mm-waves, up to infrared and optical frequencies.

Conventional frequency selective surfaces are designed to operate in a particular frequency range, which is determined by the size and the arrangement of the antenna elements and the size of the array. The operating frequency of a particular surface cannot be changed and therefore, when it is necessary to change the frequency of operation, the original surface has to be replaced with another having a different frequency response. This is undesirable in practice since the

surface is generally permanently mounted in an antenna installation and must be accurately aligned. Further, when a single array of very long dipoles is used, an inductive effect is introduced due to the relative proximity of the ends of adjacent dipoles, which destroys the resonance.

According to the present invention, there is provided a reconfigurable frequency selective surface comprising at least two arrays of elements, the arrays being arranged in close proximity with one another so that elements of a first array are closely coupled with elements of a second array adjacent to the first array, the first array being displaceable with respect to the second array to adjust the frequency response of the surface.

The frequency selective surface allows the frequency response of an antenna installation to be reconfigured without having to replace one surface with another. The inductive effect, found with single arrays, does not occur, and there is no major deterioration in the band widths or band spacing ratio as the displacement increases. The response of the reconfigurable surface is therefore stable throughout the frequency range.

The first and second arrays may be substantially parallel with one another.

The array elements may be conductive elements on a dielectric substrate, or apertures in a conductive substrate, or a combination of the above.

The first and second arrays may have a separation of no more than 0.03 wavelengths, and preferably no more than 0.003 wavelengths of the electromagnetic waves having the resonant frequency of the surface. For example, when microwaves of frequency 30GHz are to be reflected, the separation is advantageously no more than 0.225mm and preferably no more than 0.025mm.

The first array may be displaceable relative to the second array in a direction parallel to the surfaces of the arrays. Alternatively, the frequency selective surface may be reconfigured by rotating the first array with respect to the second array, or by altering the distance and/or the medium separating the first array from the second array. Using that configuration, there is no limit to the distance separating the arrays.

The array elements may be parallel linear dipoles, and the at least one array may be displaceable in the longitudinal direction of the linear dipoles.

According to the present invention there is further provided a method of reconfiguring a frequency selective surface comprising at least two arrays of elements arranged in close proximity with one another so that the elements of a first array are closely-coupled with elements of a second array adjacent to the first array, wherein the first array is displaced with respect to the second array to adjust the frequency response of the surface.

According to the present invention there is further

provided a method of reconfiguring a beam associated with a grating lobe, wherein the periodicity of a reconfigurable frequency selective surface as described above is adjusted by altering the relative positions of the first and second arrays of the frequency selective surface.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, of which:

Figure 1 is a perspective view of a frequency selective surface;
Figure 2 is a cross-section through the surface;
Figure 3 is a diagrammatic view of a part of the surface;
Figure 4 shows the frequency response of a frequency selective surface, and
Figure 5 shows the variation of the frequency response as the surface is reconfigured.

As shown in figure 1, the frequency selective surface consists of two parallel arrays 1,2 of elements 3. The array elements 3 may be electrically conductive elements, such as dipoles printed on a dielectric substrate or, alternatively, they may be apertures, such as slots, formed in a conductive surface (Babinet's compliment of the former). The two arrays 1,2 are arranged in close proximity with one another, so that the elements 3 of the first array 1 are closely coupled with

the elements of the second array 2. The separation S of the arrays is as small as possible, whilst ensuring that the elements of the first array 1 are electrically insulated from the elements of the second array 2, and will generally be of the order of 0.03 wavelengths or less, although this will depend on the particular array design, and the dielectric constant of the substrate.

The second array 2 is displaceable relative to the first array 1 by a small distance DS. In the embodiment shown in figure 1, the second array 2 can be displaced transversely, parallel to the surfaces of the arrays, in the direction of the Y-axis. Other types of displacement are, however, possible: for example, the second array 2 could be displaced in the direction of the X-axis or the Z-axis (thereby altering the distance S separating the two arrays) or it could be rotated about the Z-axis, or displaced in any combination of those directions.

When the arrays 1,2 are aligned accurately with one another (so that DS=0), the elements 3 of the first array 1 lie directly over the elements of the second array 2, thereby shadowing the second array 2 from the incident electromagnetic waves. The frequency response of the surface is then similar to that of a single array and, as shown in figure 4, includes a narrow reflection band and upper and lower transmission bands. The letters f_R denote the reflection band centre frequency, which corresponds to the resonant frequency of the surface, and the letters f_T denote the frequency of the lower

transmission band. The frequencies f_R and f_T of the reflection and transmission bands are determined by the length of the antenna elements 3 and the size of the array.

As shown in figures 2 and 3, the first array 1 has a plurality of elements 3 of length L1, and the second array 2 has a plurality of elements of length L2. The separation D1,D2 and the arrangement of the elements in each of the arrays is similar, so that when DS=0 the elements of the second array 2 lie in the shadows of the elements of the first array 1.

When, as shown in figure 2, the second array 2 is displaced transversely in the direction Y by a distance DS, the ends of the elements 3 of the second array 2 then extend by a small distance DL beyond the ends of the elements of the first array 1. Since the elements of the two arrays are closely coupled, this produces an increase in the overall effective length of each element, which affects the frequency response of the surface. As shown in figure 5, the reflection frequency f_R of the surface is shifted by an amount that is approximately proportional to the displacement DS. The frequency response of the surface can similarly be translated by displacing the second array 2 in the X or Z directions, by rotating it about the Z-axis, or by any combination of those movements.

An example of the results that can be achieved with a particular reconfigurable frequency selective surface

will now be described. The particular frequency selective surface consists of two arrays 1,2 of linear dipoles 3, printed in a square lattice on a 0.037mm thick dielectric substrate of dielectric constant 3. The geometry of the lattice unit cell is shown in figure 3, wherein L represents the length of the antenna element, W the element's width, and D the side length of the unit cell (equal to the separation of adjacent antenna elements). In the first array 1, L=4.3mm, W=0.4mm and D=6mm. In the second array 2, L=3.25mm, W=0.4mm and D=6mm. Each array is square, having sides of length 20cm, and the separation S between the arrays is about 0.225mm.

The measured and theoretical response of the surface to microwaves of frequency 12-40GHz at both normal incidence and a TE incidence of 45^{o}, with the electric field parallel to the dipoles, is shown in figure 5. By comparison, the variation in the frequency response of a single array with increasing dipole length is shown as a solid line at the top of the graph.

When the two arrays are substantially aligned, with DS in the range 0 to 0.625mm, the frequency response of the surface is similar to that of a single array having the dimensions and lattice arrangement of the first array 1. Resonance takes place at frequencies of about 31GHz and 27GHz for normal and TE:45^{o} states of incidence respectively. A frequency shift takes place as the transverse displacement DS of the second array 2 is

increased, maximum measured frequency shifts of 36% and 22% for normal and TE:45^{o} states of incidence respectively being achieved at a displacement of DS=3mm. At that displacement, the elements 3 of the second array 2 completely fill the gaps between the elements of the first array 1, and so a further increase in the displacement DS has no further effect on the frequency response of the surface.

Reducing the separation S of the arrays, thereby increasing the coupling between the elements, allows greater frequency shifts to be achieved. For example, with a separation of 0.025mm, frequency shifts of up to 60% can theoretically be obtained. The theoretical frequency shift at a separation S of 0.025mm is also shown in figure 5. There is no deterioration in the band widths or band spacing ratio (f_R/f_T) of the surface as the displacement increases and the response of the surface is therefore stable throughout the frequency range.

Various modifications of the apparatus described above are, of course, possible. Many different array geometries could be used and each array may consist either of a plurality of conductors on a dielectric substrate, or a perforated plate, or a combination of both. The antenna elements may be dipoles, cross-dipoles, tripoles, Jerusalem crosses, squares, open-ended loops or any other type of antenna element. The elements need not necessarily be arranged periodically and the

arrays may be planar or curved. The frequency selective surface may further consist of two or more closely-coupled arrays of elements, and the respective arrays may either be displaced in a direction parallel to the surfaces of the arrays, or rotated or their separation altered, or the medium separating the arrays may be adjusted (for example, by adjusting its dielectric constant).

The relative displacement of the two arrays may be controlled in various different ways. For example, piezoelectric actuators can be used to control the precise relative movement of the arrays, and the arrays can be printed directly onto the piezoelectric material. The frequency selective surface may have piezoelectric actuators positioned at some sub-areas of its surface, i.e. not everywhere on its surface. Such an arrangement could, for example, be used to align a FSS on a satellite. Alternatively, the arrays can be mounted at a small separation and air pumped from the gap between the arrays to alter their separation.

Another application of the reconfigurable frequency selective surface is to reconfigure the beam associated with grating lobes. Grating lobes are radiated by the frequency selective surface when the wavelength at which the surface is operating is approximately equal to or smaller than the separation of the elements in the surface (the periodicity of the surface). The spatial position of the grating lobes depends in part on the

periodicity of the surface, and since the periodicity can be adjusted by moving one of the arrays relative to the other one, the direction of the beam associated with those lobes can be adjusted simply by altering the relative positions of the arrays. The operating frequency can be kept fixed, and the transmitted or reflected beam can be scanned over a range or adjusted according to the changes in the periodicity, thereby providing a periodicity scan array.

Claims:

1. A reconfigurable frequency selective surface comprising at least two arrays of elements, the arrays being arranged in close proximity with one another so that elements of a first array are closely coupled with elements of a second array adjacent to the first array, the first array being displaceable with respect to the second array to adjust the frequency response of the surface.

2. A surface as claimed in claim 1, in which the first and second arrays are substantially parallel with one another.

3. A surface according to claim 1 or claim 2, in which the elements are conductive elements on a dielectric substrate.

4. A surface according to claim 1 or claim 2, in which the elements are apertures in a conductive substrate.

5. A surface according to any one of the preceding claims, in which the first and second arrays have a separation of no more than 0.03 wavelengths of the electromagnetic waves having the resonant frequency of the surface.

6. A surface according to claim 5, in which the first and second arrays have a separation of no more than 0.003 wavelengths of the electromagnetic waves having the resonant frequency of the surface.

7. A surface according to any one of the preceding claims, in which the first array is displaceable relative to the second array in a direction parallel to the surfaces of the arrays.

8. A surface according to any one of the preceding claims, in which the separation of the first array with respect to the second array is adjustable.

9. A surface according to any one of the preceding claims, in which the medium separating the arrays is adjustable.

10. A surface according to any one of the preceding claims, in which the first array is rotatable with respect to the second array.

11. A surface according to any one of the preceding claims, in which the elements are parallel linear dipoles.

12. A surface according to claim 11, in which the first array is displaceable with respect to the second array in

the longitudinal direction of the linear dipoles.

13. A method of reconfiguring a frequency selective surface comprising at least two arrays of elements arranged in close proximity with one another so that the elements of a first array are closely-coupled with elements of a second array adjacent to the first array, wherein the first array is displaced with respect to the second array to adjust the frequency response of the surface.

14. A method according to claim 13, in which the first array is displaced relative to the second array in a direction parallel to the surfaces of the arrays.

15. A method according to claim 13 or claim 14, in which the separation of the first array with respect to the second array is adjusted.

16. A method according to any one of claims 13 to 15, in which the medium separating the arrays is adjusted.

17. A method according to any one of claims 13 to 16, in which the first array is rotated with respect to the second array.

18. A method according to any one of claims 13 to 17, in which the array elements are parallel linear dipoles and

the first array is displaced in the longitudinal direction of the linear dipoles.

19. A method of reconfiguring a beam associated with a grating lobe, wherein the periodicity of a reconfigurable frequency selective surface according to any one of claims 1 to 12 is adjusted by altering the relative positions of the first and second arrays of the frequency selective surface.

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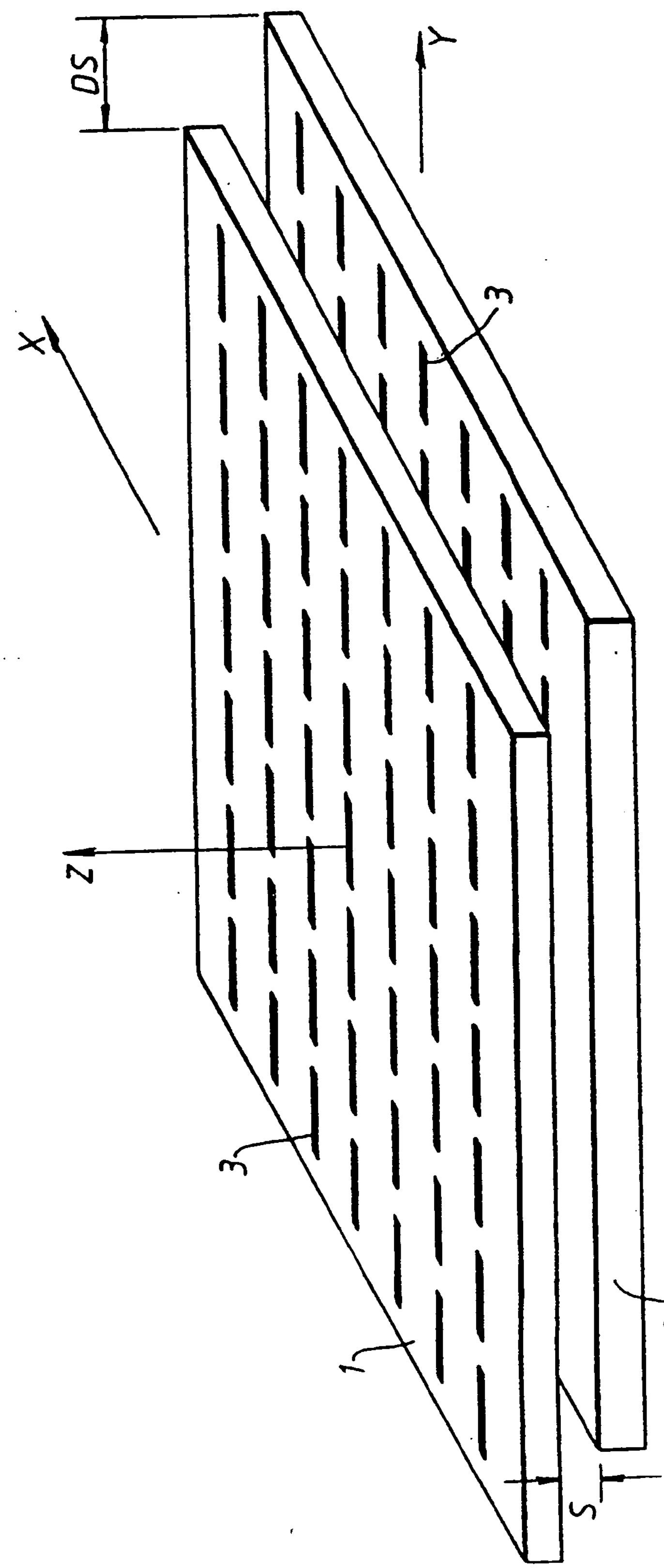

Fig.1.

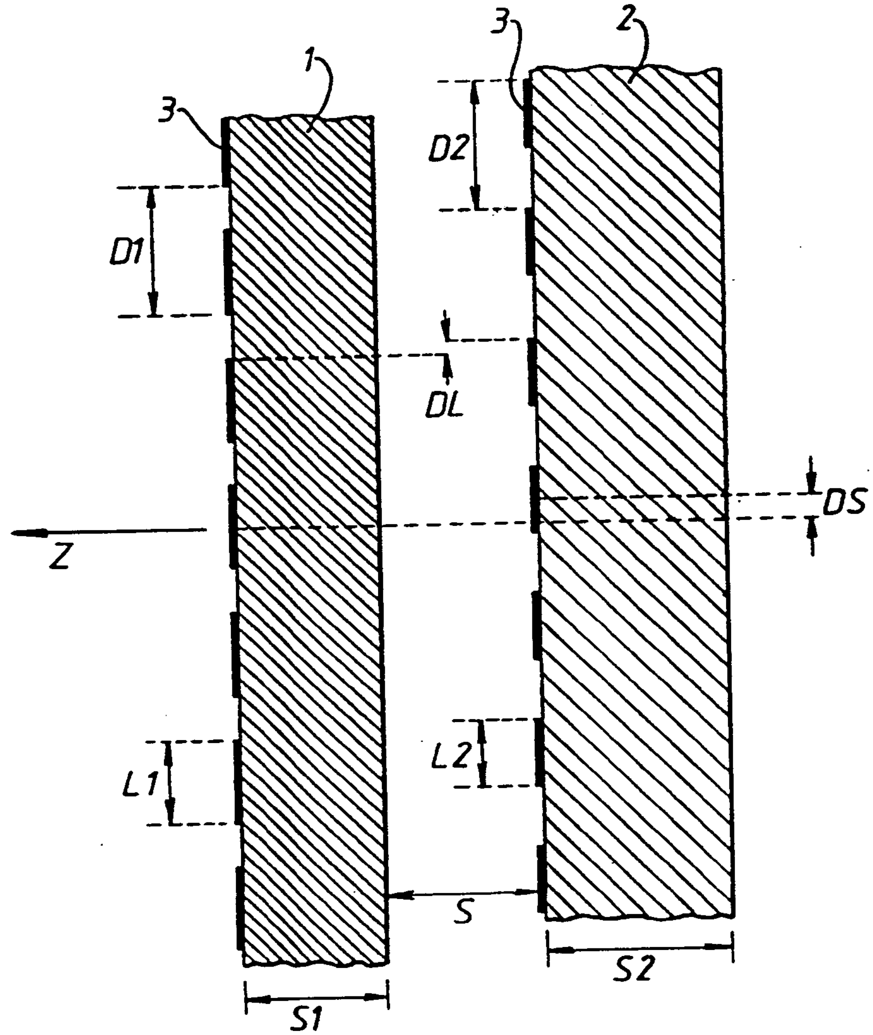

Fig.2.

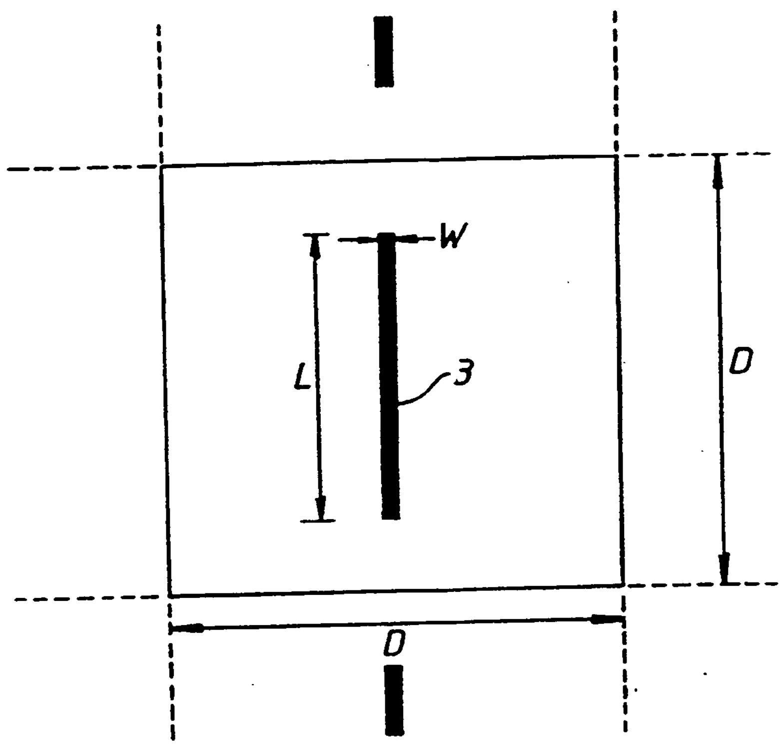

Fig. 3.

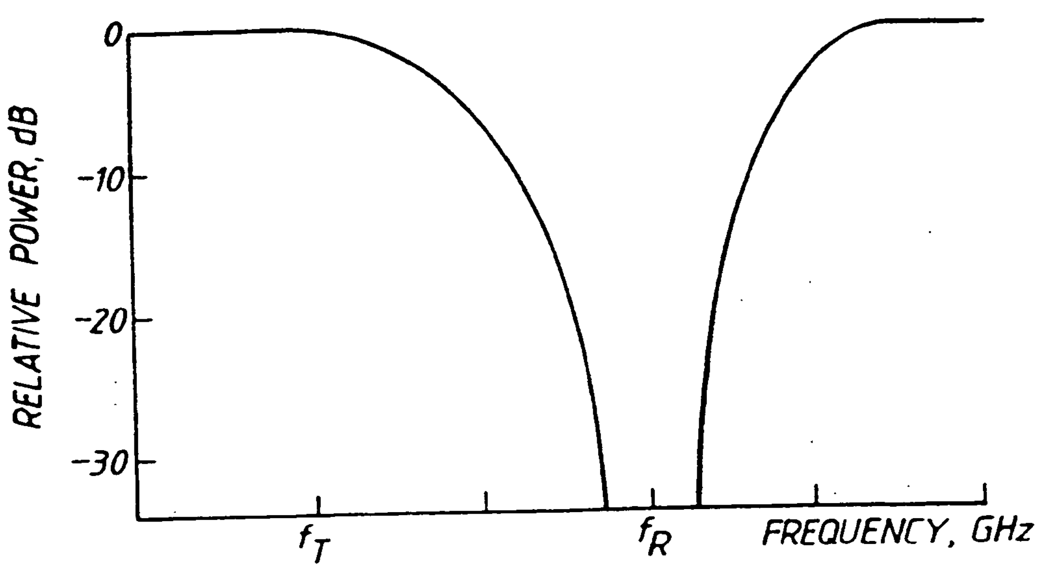

Fig. 4.

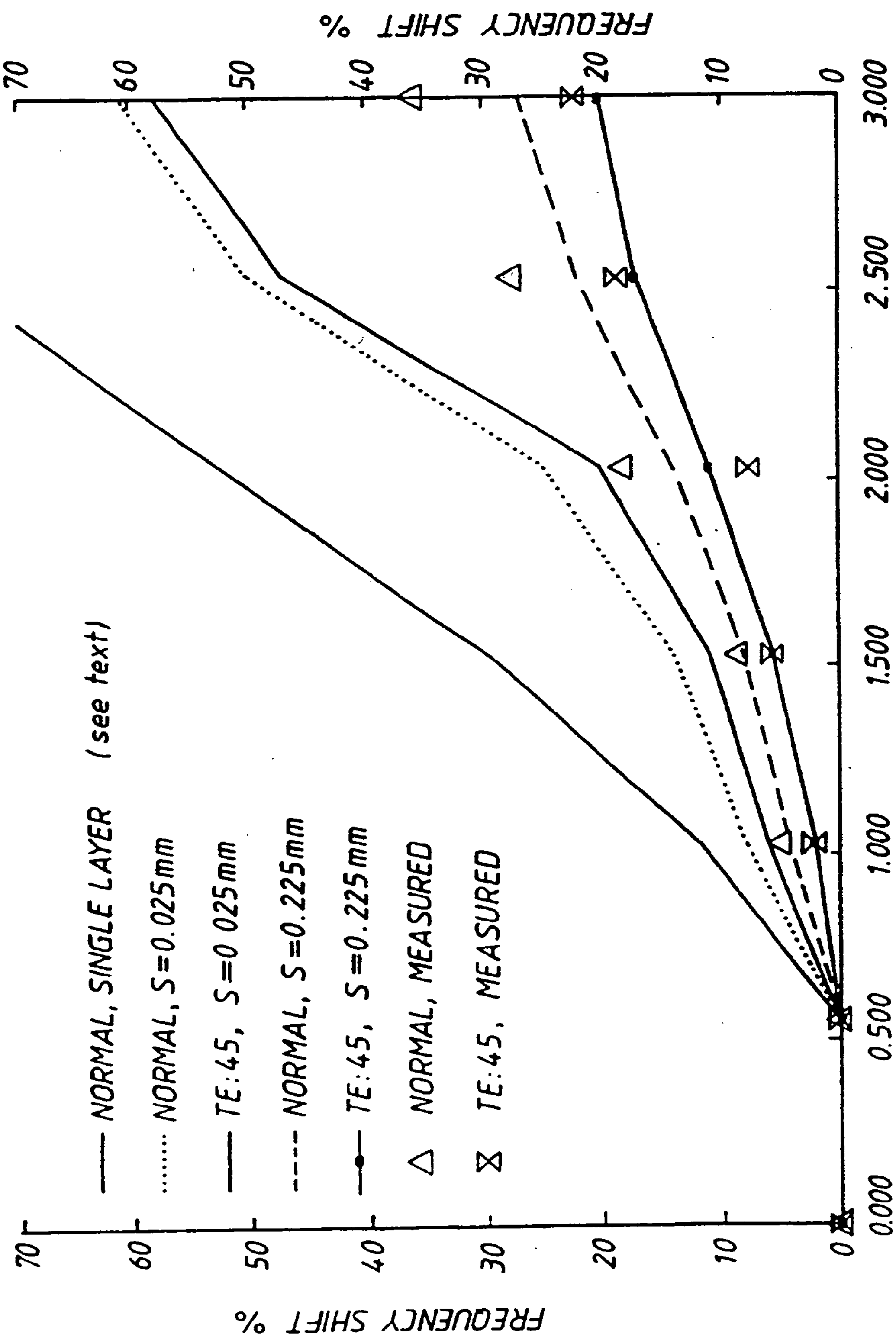
FREQUENCY SHIFT %
70
60
50
40
30
20
10
0
0.000
0.500
1.000
1.500
2.000
2.500
3.000
DS mm
— NORMAL, SINGLE LAYER (see text)
NORMAL, S=0.025mm
TE:45, S=0 025mm
NORMAL, S=0.225mm
TE:45, S=0.225mm
NORMAL, MEASURED
TE:45, MEASURED

Fig. 5.

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 92/01172

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 H01Q15/00; H01P1/20; G02B5/26

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	H01Q ; H01P ; G02B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category[o]	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
X	EP,A,0 468 623 (BRITISH AEROSPACE) 29 January 1992	1-3, 7-10, 13-17,19
Y	see abstract see column 3, line 22 - line 45; figures 1,2 see column 4, line 4 - line 39 ---	11,12,18
Y	US,A,4 307 404 (YOUNG) 22 December 1981 see column 1, line 38 - line 68; figures 3,7-9 ---	11,12,18
A	GB,A,600 433 (BOOKER) 8 April 1948 see page 1, left column, line 21 - right column, line 87; figures 1-6 --- -/--	1,13,19

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IV. CERTIFICATION

1

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
26 FEBRUARY 1993	5. 03. 93
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	ANGRABEIT F.F.K.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	CONFERENCE PROCEEDINGS 19TH EUROPEAN MICROWAVE CONFERENCE September 1989, LONDON/UK pages 863 - 868 VARDAXOGLOU ET AL. 'SINGLE AND DOUBLE LAYER FSS OF TRIPOLE ARRAYS' see page 865, paragraph 3.2 - page 866; figure 1	1,5,6
E	GB,A,2 253 519 (LOUGHBOROUGH UNIVERSITY OF TECHNOLOGY) 9 September 1992 see the whole document	1-19

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

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SA 61614

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The members are as contained in the European Patent Office EDP file on 26/02/93
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0468623	29-01-92	None	
US-A-4307404	22-12-81	None	
GB-A-600433		None	
GB-A-2253519	09-09-92	None	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82